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## UPPER METER PROCESSES:
## SHORT WIND WAVES, SURFACE FLOW, AND MICRO-TURBULENCE

**FINAL REPORT for ONR N00014-93-1-0093**

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### SUMMARY

The primary goal of this project was to advance the knowledge of small-scale air-sea interaction processes at the ocean surface, focussing on the dynamics of short waves, the surface flow field and the micro-turbulence. Since ground truth of the sea surface is still widely missing, a better understanding of the physics of these upper meter processes is of very important for the study of air-sea gas and momentum exchange and the electromagnetic backscatter from the sea surface.

This objective was achieved through the development and use of novel experimental methods—based on optical imaging techniques—to measure short wind waves, the turbulence, and the surface flow field at the ocean interface. Within the framework of this project, we developed a drifting buoy with an imaging wave slope gauge (ISG) and an infrared imaging system (CFT). This system allows for the simultaneous measurement of the surface wave slope and the microscale temperature fluctuations within the same foot print. The area extended data from these instruments are combined with meteorological ground truth to obtain a better insight into the dynamics of the interaction between short wind waves with the turbulent drift layer at the ocean surface. Wave slope image data were recorded in the field and compared to the available laboratory data.

### TASKS COMPLETED:

Deployments of the wave imaging buoy from the Scripps Pier were accomplished for swells exceeding six feet and wind speeds ranging from 2 to 8m/s. The buoy acceleration and slope data recorded during these deployments showed that the wave imaging buoy also has excellent wave following capabilities. High quality wave slope and temperature image data can be acquired even during daylight hours, except for very bright, sunny skies. In these cases sun glitter dominated the wave slope images.

After completing the development of the wave imaging buoy, we concentrated our efforts in the last year on the further analysis of the wave image data from the laboratory. Therefore, no additional field measurements were performed.

1. We have evaluated the wave slope image data from measurements in 1994 and 1998 at the Wallops Island wind wave facility. The spectra are mostly short fetch data, but include several measurements with surface slicks and background waves.

2. We have initiated a cooperation with V. Kudryavtsev and V. Makin, to compare the equilibrium wavenumber spectra from our laboratory measurements with their coupled wind-wave model [Makin and Kudryavtsev, 1999; Kudryavtsev et al., 1999]. For this purpose, we generated recalibrated and reevaluated the directional wavenumber spectra from the Heidelberg, Delft, Marseille, and Wallops facilities for all available wind speed and fetch conditions to ensure both, the correct spectral scaling and that all wave data were processed identically. Previously, some data were calibrated in the spectral domain, while other data were normalized in the spatial domain and the spectral windowing was not identical for all cases. All spectra were then output in Matlab format, so that it is now possible to upload them directly into their model code.

3. We developed a new technique to analyze nonlinear water waves and to extend the measureable wavenumber range of the imaging slope gauge data to lower wavenumbers. This new filter method makes use of image sequences rather than still images and separates different wave trains based on their respective phase velocities and propagation directions in the image stack. Thus, it is now possible to resolve waves that are longer than the original image size.

**SCIENTIFIC RESULTS:**

The results from the laboratory data analysis show that short wind waves (2-10cm wavelength) in wind/wave facilities are predominately dispersive rather than bound by the dominant wave components. Plant et al. [1999] have reported similar findings. The capillaries (< 1 cm) are closely resonant with the longer wave components. They can extract energy directly from the long waves and may be important dissipation sources of longer wave components, especially at low wind speeds [Zhang et al., 1999].

Kudryavtsev and Makin modified their model for short fetch conditions by taking the spectral peak of the dominant waves into account. This is possible, because the model assumes a balance between the generation of parasitic capillaries and the wind input in the short gravity wave regime. The influence of the fetch is therefore contained in the dominant wave frequency for a given friction velocity. This work is still in progress, but preliminary results indicate very good agreement, not only of the general shape of the model and measured spectra, but also with regard to their wind speed dependence.

So far, the novel technique to analyze wave slope image sequences has been applied to artificial test image sequences only. These studies demonstrate that a separation of waves travelling at different speeds and in different directions can be achieved while preserving the shape of the wave profile [Hilsenstein, 2000]. Therefore, such a method gives much more insight into the nonlinear interaction of water surface waves than conventional Fourier transform techniques and power spectra, and should prove especially useful in the investigation of bound and free waves.

## SIGNIFICANCE:

Recent efforts in modeling the radar return from the sea surface, divide the water surface into patches of free and bound waves, and argue that the turbulence associated with the bound waves suppresses the generation of free waves by the wind. Under these assumptions, their Bragg/composite surface scattering model can account for the decrease in the polarization ratios with increasing wind speed for laboratory settings [Plant et al., 1999]. Their estimates of the ratios of free versus bound waves is based on laboratory data only, and the authors mention that these estimates are likely to be very different in the field. Wave breaking statistics and surface wave spectra from the field are also needed in modeling air-sea momentum fluxes [Hara and Belcher, 1999] and wind-wave coupling [Makin and Kudryavtsev, 1999; Kudryavtsev et al., 1999]. Using the combination of optical and infrared imaging techniques, the mechanisms of surface renewal—free convection, rain, breaking waves, or microscale breaking— can be identified and quantified in the field. All these studies require the kind of high-resolution wave field the wave imaging buoy can supply.

The IR surface turbulence imaging technique is now being used by K. Melville (Scripps Institution of Oceanography) to study the generation of Langmuir circulation and by A. Jessup (APL, University of Washington, Seattle) to study the influence of microscale wave breaking on air-sea gas transfer. During the course of this project we have designed wave slope imaging systems for K. Melville (Scripps Institution Oceanography), N. E. Huang (NASA/Goddard Space Flight Center), and S. Long (NASA/Wallops Flight Facility), and instructed them on how to use the wave slope imaging technique. Last year, a new design of a color imaging slope gauge was completed for M. Donelan's wind/wave facility at RSMAS (University Florida, Miami) and just recently F. Veron (University of Delaware) has inquired about such a system. Given the number of researchers that are now using the observational techniques developed by our research group, it is fair to say that this ONR-sponsored research has improved the experimental investigation of small-scale air-sea interaction processes significantly.

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